

AXAF

The Advanced X-Ray Astrophysics Facility



AXAF

The Advanced X-Ray Astrophysics Facility

Determine the nature of celestial objects



Characterize the physical processes that occur in space



Understand the history and evolution of the Universe



Test the fundamental laws of physics

Our Highest Priority New Observatory

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X-rays are produced by violent, energetic, and explosive phenomena in the Universe. The Advanced X-Ray Astrophysics Facility (AXAF) is an orbiting observatory designed to view these X-rays. The National Academy of Sciences Survey Committee on Astronomy and Astrophysics has recommended AXAF as the #1 priority among all major new astronomy programs. The scientific importance of AXAF was also highlighted by the Academy's Survey Committee on Physics.

Why has AXAF earned such enthusiastic support, not only among astronomers, but also broadly within the nation's scientific community?

★ AXAF is the premier observatory for X-ray astronomy, a major field of research that has revolutionized our perception and understanding of the Universe.

★ AXAF is an essential component in the set of complementary space observatories necessary for a well-coordinated look at the Universe across the electromagnetic spectrum.

★ AXAF's value reaches beyond astronomy; it is an important new tool for basic research in plasma physics, the fundamental properties of matter, and the laws of physics.

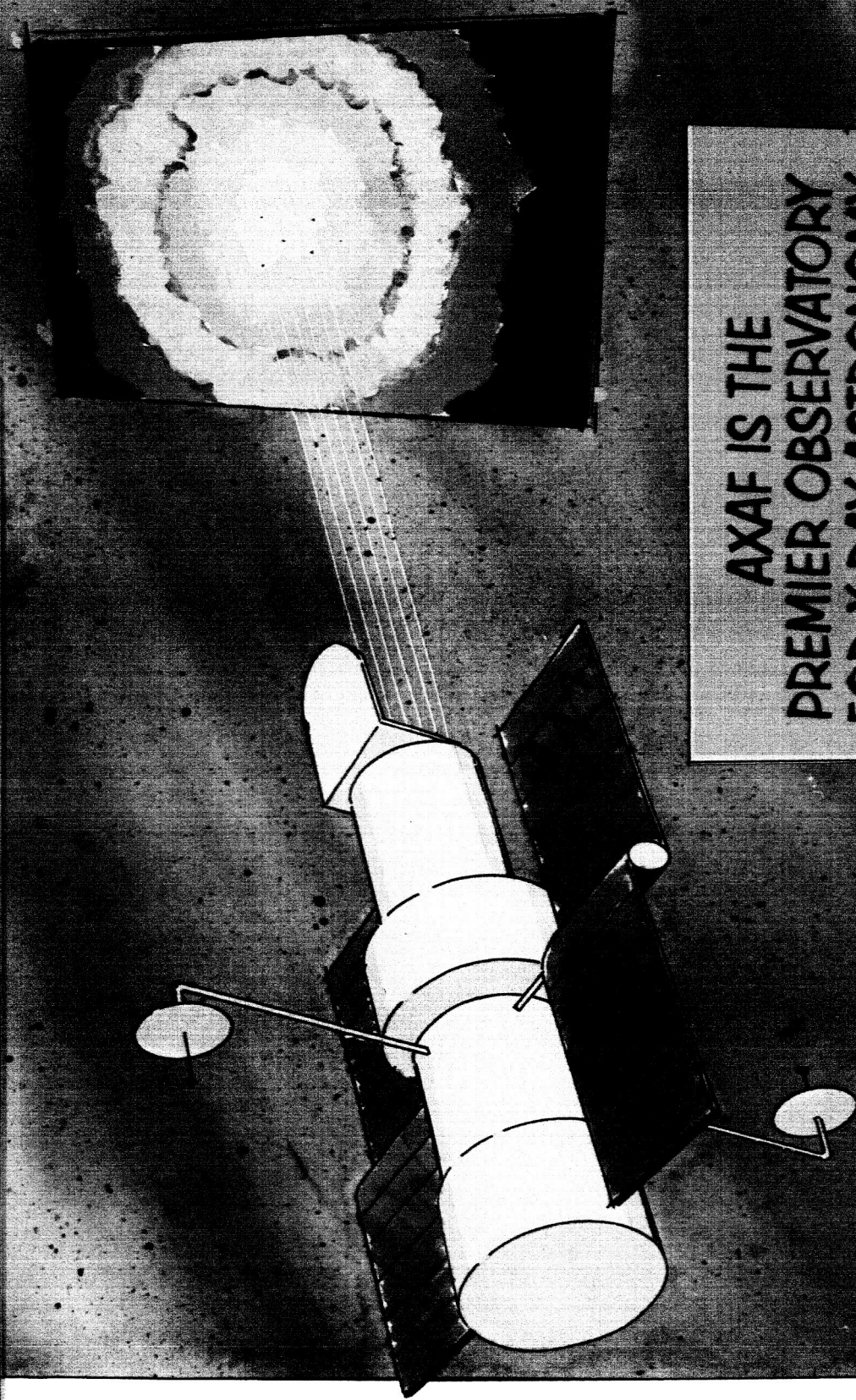
★ AXAF is a long-lived observatory, providing the opportunity for systematic study and understanding of discoveries; it is also a step toward the goal of achieving a permanent presence in space.

★ AXAF builds upon the nation's experience, talent, and resources for space science to maintain United States leadership in the exploration of the Universe.

★ AXAF is ready to be built; the scientific foundation and basic technology have been proven in a spectacularly successful prior NASA program, and the additional studies and technology development necessary to begin AXAF have been completed.

AXAF will be used to study fascinating astronomical objects such as spinning neutron stars, black holes, and quasars. It will be used to answer fundamental questions about the nature of the Universe. Operating in space for fifteen years, AXAF will be a program of exploration, discovery, and systematic study.

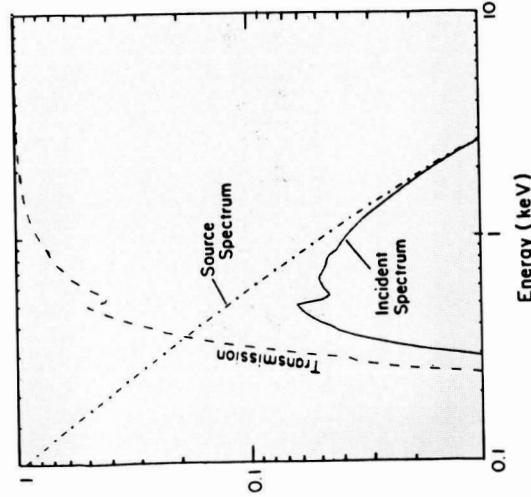
SEEING THE UNIVERSE IN X-RAYS



AXAF IS THE
PREMIER OBSERVATORY
FOR X-RAY ASTRONOMY.

AXAF and X-Ray Astronomy

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The X-ray portion of the electromagnetic spectrum is rich in information. Here the dotted lines show a spectrum from a cluster of galaxies, with a curve indicating the transmission of this flux through the interstellar medium in our galaxy. The solid curve is the product of these functions and determines the relative number of incident photons. The soft X-ray spectrum is clearly optimal for gathering information. The sensitivity of AXAF thus offers a means of probing the Universe in a critical wavelength region.

The new science of X-ray astronomy began in 1962 with the launch of an X-ray detector aboard a rocket. X-rays are a part of the electromagnetic spectrum (the wavelengths of light) not visible to the eye or to a conventional telescope. X-rays produced in space are absorbed by the atmosphere and thus cannot be detected from the ground. At the time of this first experiment, cosmic X-ray sources were unknown; however, early discoveries made it clear that varied X-ray phenomena are widespread throughout the Universe.

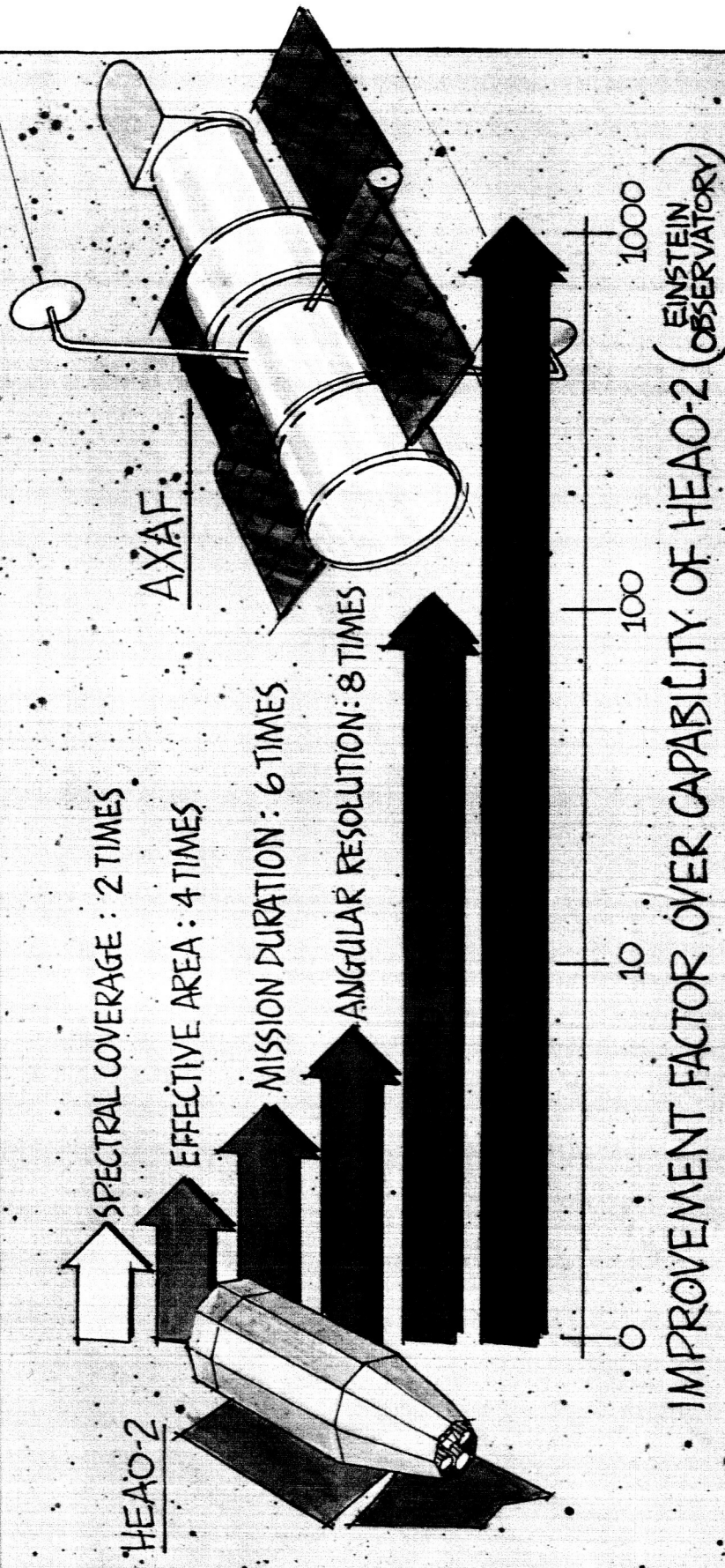
We now know of thousands of X-ray emitting objects, including stars in our galaxy, galaxies, and distant quasars. X-rays are produced in settings where temperatures reach millions of degrees, where particles can be accelerated by gravity to nearly the speed of light, and where magnetic fields are more than a trillion times stronger than the Earth's. Cosmic X-ray sources are studied in three ways: by obtaining images with special optics and detectors, by measuring the X-ray spectrum (the number of X-rays produced at each energy), and by monitoring changes in X-ray brightness over time. These methods combined yield information about the structure and dynamics of X-ray sources.

The best view of the Universe in X-rays was obtained from 1978 to 1981 by NASA's orbiting High Energy Astronomy Observatory (HEAO-2), the Einstein Observatory. This satellite had a moderately sensitive X-ray telescope which focused X-rays from celestial objects into vivid images for the first time, revealing more new and different X-ray sources than had ever been imagined. These discoveries established the importance of X-ray astronomy, but because of its limited capability and short lifetime, the Einstein Observatory mission raised as many questions as it answered.

AXAF is the next generation X-ray observatory, the logical successor to the highly successful HEAO-2 mission. AXAF is 100 times more powerful for detecting X-rays and will provide images almost 10 times sharper. It will double the slice of the electromagnetic spectrum that can be observed in X-rays, with up to a thousand-fold improvement in ability to distinguish different energies over this spectral range.

A wealth of knowledge about the Universe is accessible through the X-ray window; AXAF is a unique tool for gaining that knowledge.

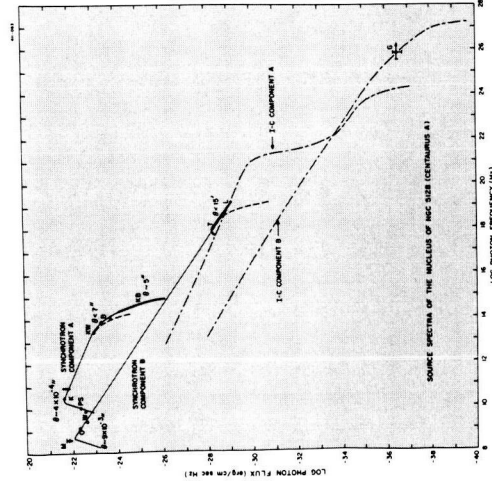
AXAF: MAJOR ADVANCES IN CAPABILITY



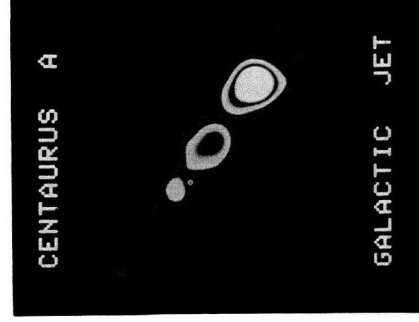
ADVANCES IN MEASUREMENT
CAPABILITY INEVITABLY LEAD
TO ADVANCES IN KNOWLEDGE.

AXAF and the Great Observatories

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An X-ray image and the energy spectrum of radiation from the unusual galaxy Centaurus A reveal a central powerhouse, possibly a supermassive black hole, that is producing jets of high energy particles. Combined high sensitivity studies across the electromagnetic spectrum of the emission from both the central region and the jets are needed to understand the nature of the central object and the mechanism by which the high energy particles are accelerated.



Progress occurs in astrophysics and the other sciences as information is gained through many channels. The nation's strategy for astrophysics research in the rest of this century relies on a set of complementary observatories in space, each dedicated to viewing the Universe through a different window in the spectrum:

- ★ Gamma Ray Observatory (GRO) — gamma rays
- ★ Advanced X-Ray Astrophysics Facility (AXAF) — X-rays
- ★ Hubble Space Telescope (HST) — visible light
- ★ Space Infrared Telescope Facility (SIRTF) — infrared radiation

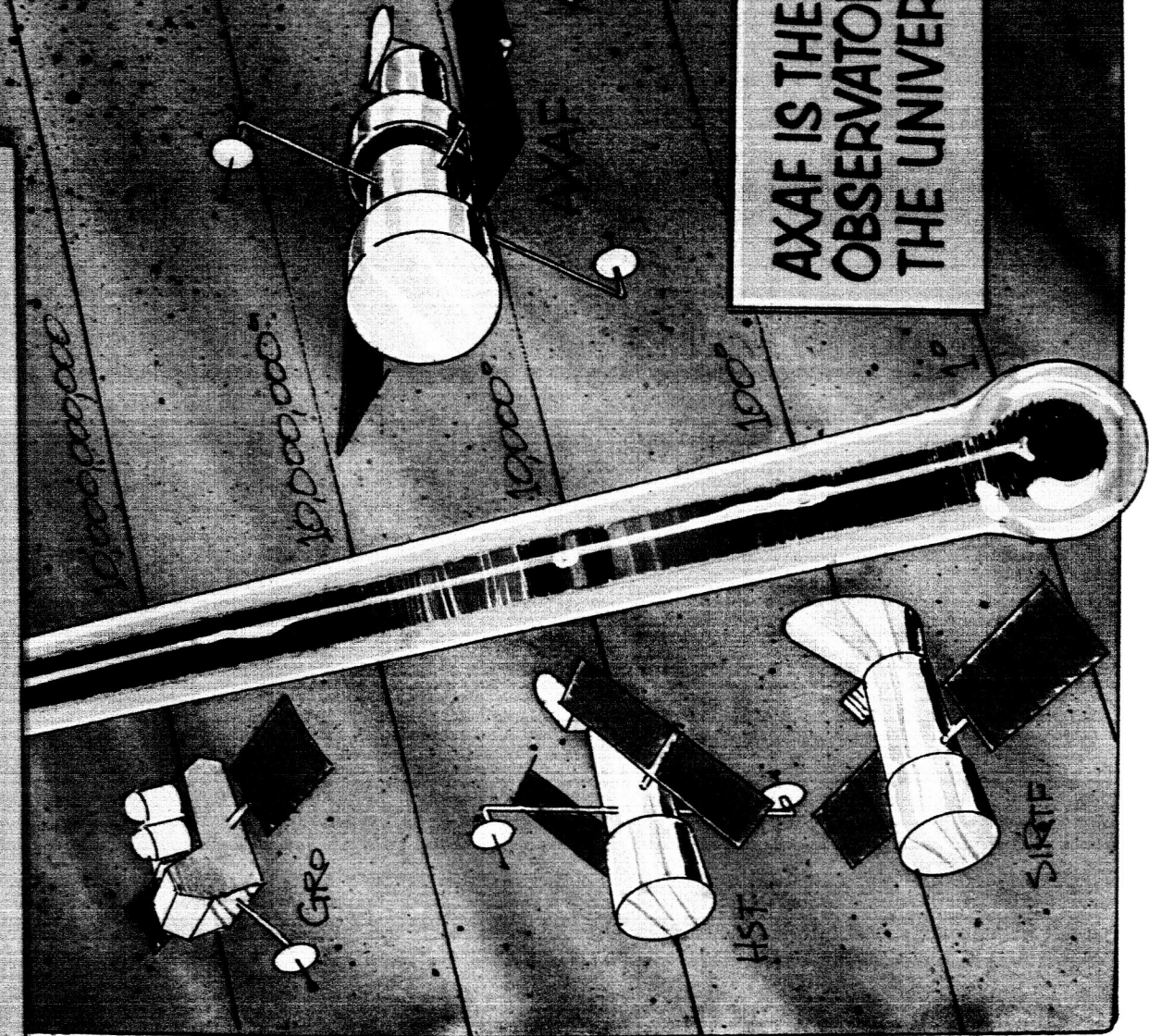
As part of this multispectral campaign, two powerful new ground-based observatories are envisioned: the Very Long Baseline Array (VLBA), an intercontinental network of radio telescopes, and the National New Technology Telescope (NNTT), a very large optical telescope.

Each of these observatories is designed to be the best of its kind. With improvements in sensitivity and resolution much beyond their predecessors, the Great Observatories will enable us to see farther into the Universe, and in more detail, than we ever have. Together, they will produce a golden age of astronomy unrivaled by any previous era of discovery.

AXAF is a crucial member of this family of Great Observatories, the only one designed to study the Universe in X-rays. Maximum scientific benefit will be achieved when all of these observatories operate simultaneously, each complementing the others. Just as we depend on all of our senses to perceive the world around us, so we need all of the Great Observatories working together to understand the Universe.

The Hubble Space Telescope and Gamma Ray Observatory are already nearing completion; AXAF will join them soon in the campaign to explore the Universe across the spectrum.

EXPLORING THE UNIVERSE ACROSS THE SPECTRUM



- ☒ NORMAL STARS
- ☒ NEUTRON STARS
- ☒ BLACK HOLES
- ☒ GLOBULAR CLUSTERS
- ☒ GALAXIES
- ☒ QUASARS
- ☒ GALAXY CLUSTERS

AXAF IS THE ONLY GREAT
OBSERVATORY THAT CAN VIEW
THE UNIVERSE IN X-RAYS.

The Universe is a vast natural laboratory where scientists can observe phenomena in a wide variety of environments. Especially important are the extreme conditions that

cannot be reproduced in laboratories and particle accelerators here on Earth. Studies possible with AXAF will have a direct bearing on several scientific fields, including plasma physics, atomic and nuclear physics, general relativity, elementary particle physics, and cosmology.

X-ray emitting gases are so hot that the atoms have become disassociated, leaving free electrons and partially or completely ionized atoms. Detailed understanding of these gases, called plasmas, is the focus of nuclear fusion research, which one day may provide a plentiful source of energy. Plasmas abound in the Universe, and all the high temperature plasmas are strong X-ray sources. AXAF can obtain the detailed diagnostics to study these plasmas and provide important data to test and refine theoretical models.

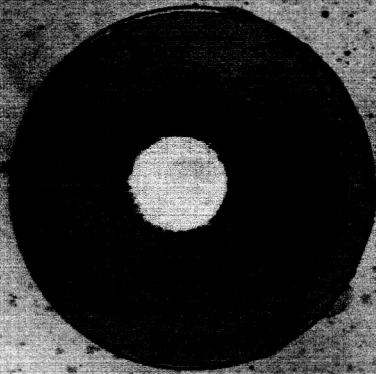
The detailed study of X-ray emission from neutron stars exemplifies how research with AXAF will impact atomic, nuclear, gravitation, and elementary particle physics. Some spinning neutron stars, as massive as our sun but only ten kilometers in diameter, orbit and draw matter from companion normal stars, releasing copious amounts of X-rays as the matter comes crashing down to the neutron star's surface. These exotic objects are a prime laboratory for the study of matter and radiation under extreme physical conditions.

AXAF's unique capability to locate and measure the mass of dark matter, whose existence has been inferred, and its capability to look deep in the Universe and thus back in time have a direct bearing on cosmology and elementary particle physics and, therefore, on the validity and tests of Grand Unified Theories. These theories attempt to merge the fundamental forces of nature and form the thrust of much of the basic research in physics today.

The importance of AXAF transcends the specialized fields of X-ray astronomy and astrophysics. The National Academy of Sciences Physics Survey Committee report, "Physics Through the 1990's," which recommends a vigorous program of space observations, specifically includes AXAF.

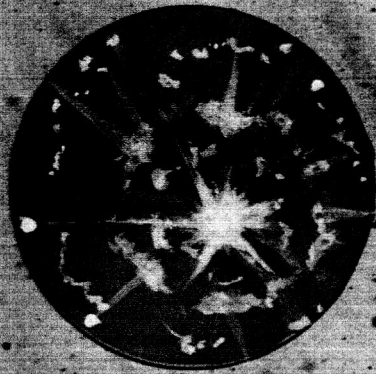
AXAF: SCIENCE IN A BROAD CONTEXT

PARTICLE PHYSICS



NEUTRON STARS

ATOMIC PHYSICS



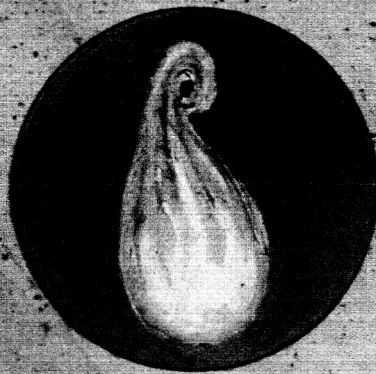
SUPERNOVA REMNANTS

PLASMA PHYSICS



CLUSTERS OF GALAXIES

RELATIVITY THEORY



BLACK HOLES

COSMOLOGY



QUASARS

AXAF IS A VERSATILE
INSTRUMENT FOR
BASIC PHYSICS
RESEARCH IN THE
LABORATORY OF SPACE.

Fascinating Science and Fundamental Questions

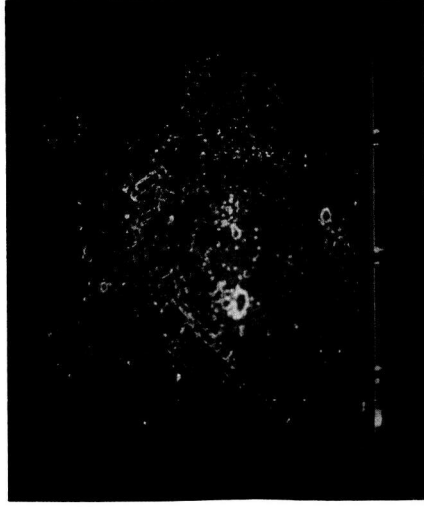
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Pioneering U.S. astronomy programs have shown that virtually every category of celestial objects emits X-rays. An investigation of the Universe in X-rays touches many subjects: the life cycles of stars and galaxies, small hot spots on the surfaces of neutron stars, large clumps of intergalactic gas, the nearest stars, the most distant quasars, the familiar sun, and black holes.

A hundred times more sensitive than any other X-ray telescope, over a broader energy range, AXAF is a great advance in X-ray astronomy. AXAF will address many intriguing problems and questions in modern astrophysics:

- ☆ How big and how old is the Universe?
- ☆ Where is the dark matter?
- ☆ Why are quasars so powerful?
- ☆ Do black holes really exist?
- ☆ Why is the sky glowing in X-rays?
- ☆ What remains when stars explode?
- ☆ How do other stars compare with the sun?
- ☆ Do exotic particles exist?

For ages we have observed what seemed to be a quiet, almost unchanging sky. The picture from AXAF will be very different: a Universe that is a strange and dynamic place of change, turmoil, and violence.



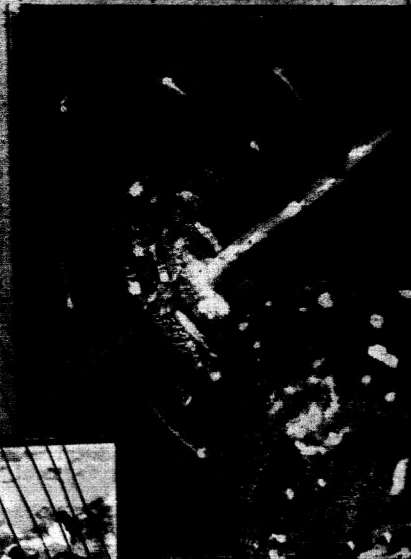
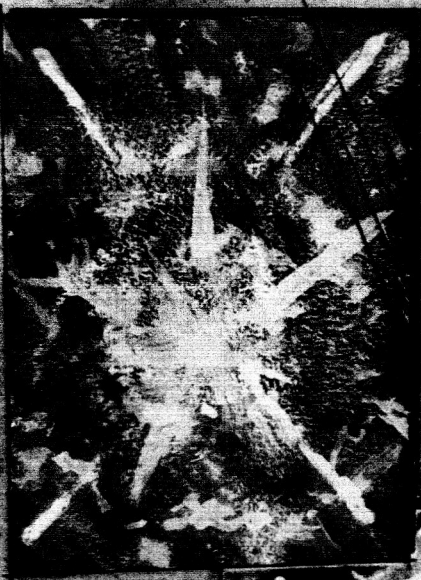
A montage of HEAO-2 X-ray images of the Large Magellanic Cloud shows several phenomena needing detailed study with AXAF: stellar coronal sources, compact objects, supernova remnants, at least one stellar mass black hole candidate, X-ray emission from hot interstellar gas, and X-ray shadows produced by cold interstellar clouds.

WHAT CAN AXAF REVEAL?



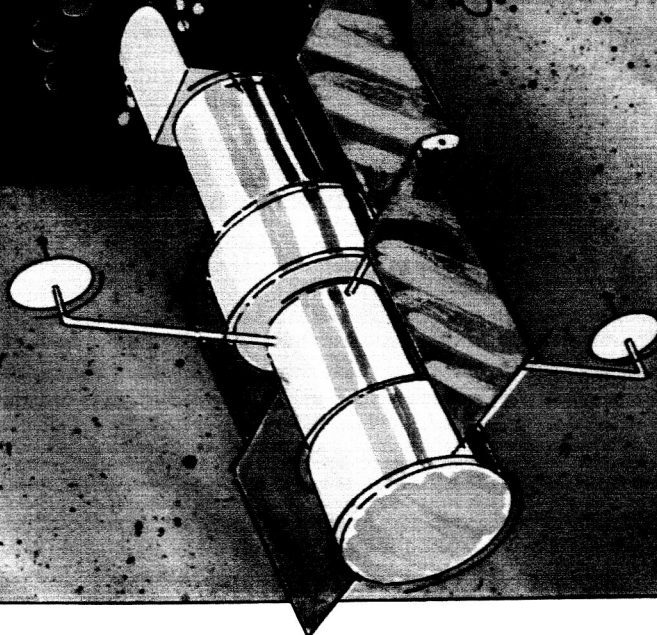
NEUTRON STAR

BLACK HOLES



DIFFUSE X-RAY BACKGROUND

STELLAR CORONAE



AXAF

The Age and Fate of the Universe

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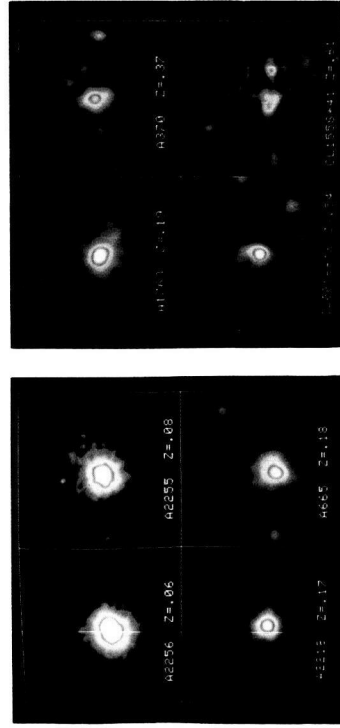
The Universe probably began with a colossal explosion, the Big Bang; radio observations have detected the afterglow of that explosion. How long ago did this happen? How fast is the Universe expanding? Will it expand forever or will it slow down, stop, and eventually collapse?

The expansion of the Universe is characterized by one of the most important numbers in astronomy, the Hubble constant, which relates distance to the speed of expansion. Precise determination of this constant has eluded astronomers despite decades of concerted effort. Current measurements differ by a factor of two, which causes uncertainty in almost every extragalactic astrophysical problem. An improved method for determining the Hubble constant is one of the primary concerns of astrophysicists today.

AXAF can provide such a method by looking at the hot X-ray-emitting gas in clusters of galaxies in conjunction with ground-based radio telescopes. X-ray images, spectra of the hot gas, and measurements of the radio waves that have interacted with the cluster's hot gas can be combined to determine the Hubble constant. Previous X-ray instruments lacked sufficient sensitivity to give a useful measurement, but the spatial and spectral resolution of AXAF are expected to give a value of the Hubble constant accurate to 10%, a factor of 10 more precise than current measurements. Furthermore, this approach to measuring the Hubble constant appears to be free of the interpretational problems that plague traditional measurements.

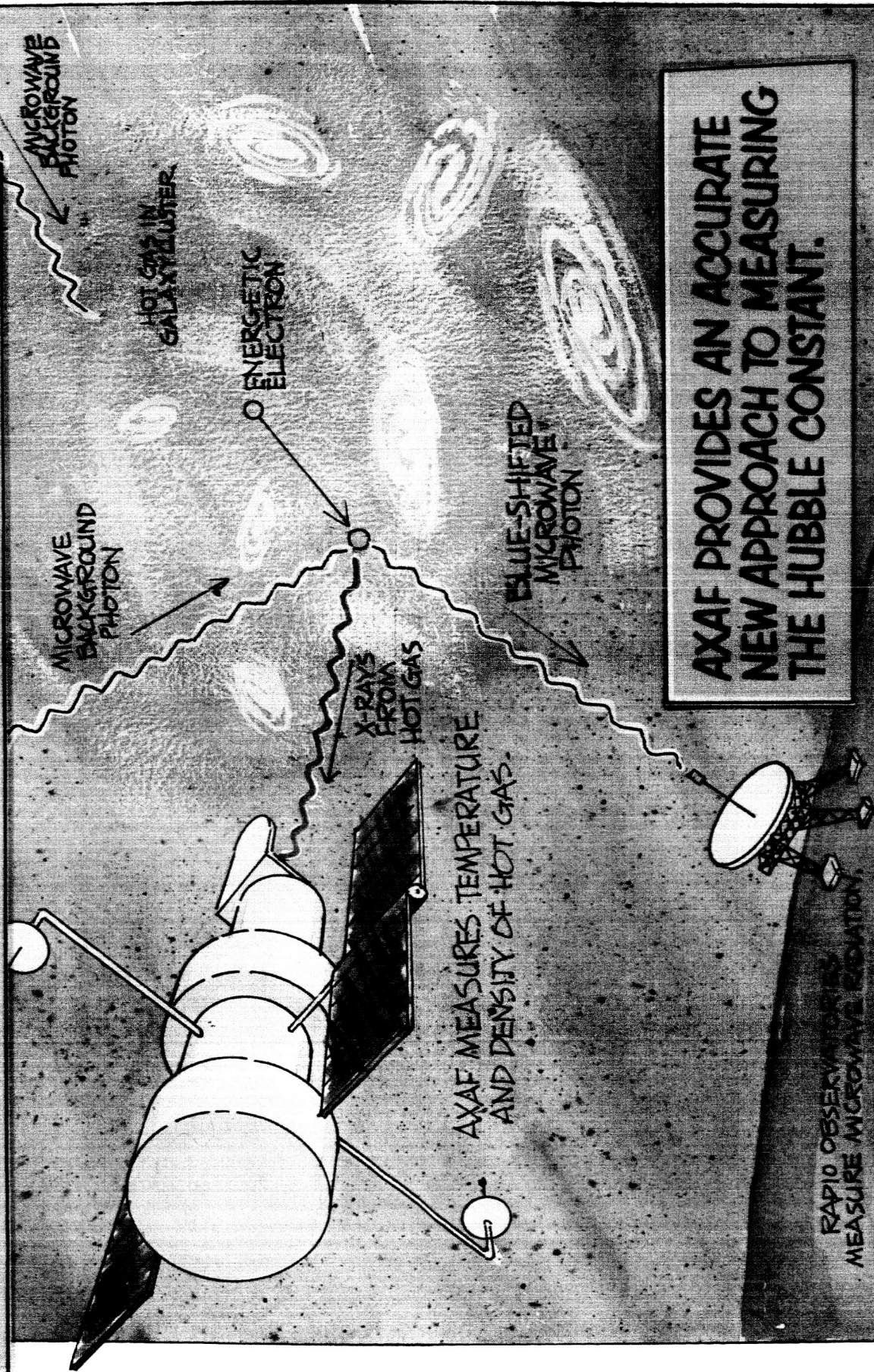
But AXAF can do still more. Because AXAF is sensitive enough to look far out in the Universe—far back in time—it will measure the expansion speed at several different times in cosmic history. This, in turn, tells us if the Universe will continue to expand forever or will eventually stop and then contract. Thus, AXAF can predict the fate of the Universe.

Wondering about the origin and fate of the Universe transcends astrophysics: it is one of the enduring pursuits of mankind. From the first person who looked at the sky to the most educated, experienced astrophysicist today, we share a collective human desire to understand our origin and our place in the cosmos. Through its power to explore the Universe in X-rays, AXAF is a new venture in this tradition.



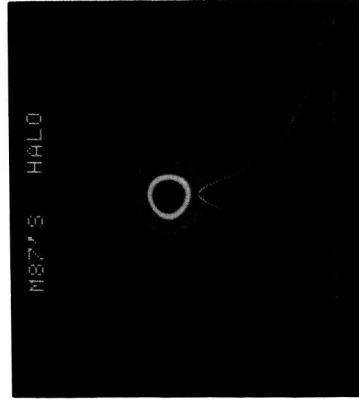
These X-ray images of clusters of galaxies at different redshifts (Z) were obtained from the HEAO-2 Observatory. Observing clusters such as these, AXAF will be able to determine with accuracy the density and temperature distribution in the intracluster gas. This information can then be combined with radio observations of the microwave decrement to measure both the Hubble constant and the deceleration parameter.

HOW BIG AND HOW OLD IS THE UNIVERSE?

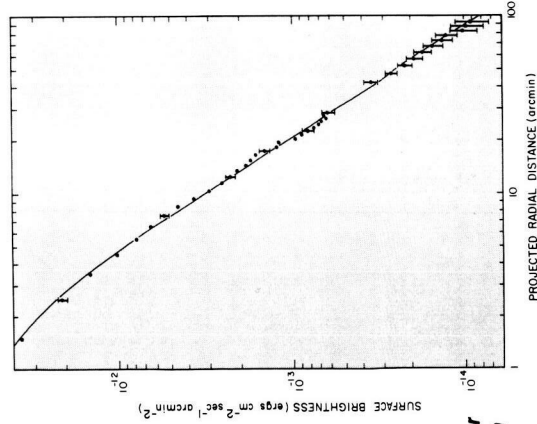


Dark Matter

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The technique for probing dark matter in galaxies is illustrated by the HEAO-2 X-ray observations of the giant elliptical galaxy M87. The X-ray image shows emission extending over a region three times larger than that from which visible light has been detected. Using the surface brightness and temperature profiles as a function of radius and the assumption that the bulk of the gas is in hydrostatic equilibrium, one can compute the total mass interior to a given radius. The total mass estimate is between 4 and 8×10^{13} times the mass of the sun. This is 100 times more mass than is determined from the visible light output of the galaxy.



One of the basic questions in astronomy is whether visible stars and galaxies represent most of the matter in the Universe or whether most of the matter is invisible (and thus referred to as dark matter). The presence of dark matter is evident through the gravitational force it exerts on other objects, such as stars, galaxies, and clusters of galaxies. Dark matter in the Universe may be in the form of asteroids, planets, dark stars, black holes, postulated new exotic particles, or other unknown kinds of matter. AXAF can lead the search for the dark matter and provide much needed data on its mass and location.

Within our own galaxy, only AXAF will have the sensitivity to search for the X-ray emission from such dark matter candidates as isolated black holes that accrete material from the interstellar medium, dark stars with bright X-ray coronae, and isolated neutron stars cooling from the high temperatures at their formation.

X-ray observations with HEAO-2 revealed that a few of the brightest, nearest galaxies are filled with very hot gas at temperatures of a few million degrees. The hot gas must be trapped inside the galaxy by gravitational force; otherwise the gas would quickly evaporate. Since the visible stars in these galaxies do not have enough mass to provide the necessary gravitational force, a certain amount of dark, invisible matter must exist between the stars. AXAF will be able to measure the mass and locate this dark matter accurately in hundreds of galaxies.

The mass within galaxies accounts for only a small fraction of the dark matter in the Universe. The presence of X-ray-emitting gas in clusters of galaxies implies the presence of still more dark matter. In this case, the dark matter accounts for a hundred times the mass seen in visible light and is distributed between the member galaxies of the cluster. AXAF will be able to "weigh" and locate the invisible matter in clusters, perhaps revealing differences among clusters that are clues to the identity of the dark matter.

Dark matter may also pervade the Universe, as it must if the expanding Universe is found to be decelerating substantially. Are there three different explanations for the dark matter in galaxies, clusters, and the Universe in general, or is it all the same? The present evidence is ambiguous, and current observations are severely limited. AXAF will provide necessary data for answering these questions.

WHERE IS THE DARK MATTER?

WITHIN CLUSTERS
OF GALAXIES?

WITHIN
GALAXIES?

INTERSTELLAR
GAS

IN ISOLATED
STELLAR
BLACK HOLES?

X-RAY
CORONA

IN LOW-MASS
STARS

AXAF DETECTS THE PRESENCE
OF DARK MATTER IN A VARIETY
OF CIRCUMSTANCES.



Quasars

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Quasars are the earliest, most distant, and most luminous objects known in the Universe. Although no larger than the solar system, they can have hundreds of times the power of an entire galaxy. The source of this immense power is still not understood.

We know little about when in the history of the Universe quasars formed, how their properties evolved in time, and what fundamental mechanism generates the incredible amounts of energy they emit. AXAF is a prime instrument for the solution of these puzzles, because quasars emit so many X-rays and AXAF's sensitivity for detecting X-rays is very high.

A number of X-ray emitting quasars were discovered with HEAO-2, and many more will be catalogued by the German ROSAT satellite. Because of its much greater sensitivity, AXAF will survey deeper into the Universe, probing a much larger volume and discovering many new quasars. Observations of very young quasars (those that are far away and thus were formed long ago) document the onset and progress of quasar formation. The comparison of nearby (old) and distant (young) quasars will indicate their evolution in time. This knowledge will provide a clue to the structure of quasars, as well as a marker of the history of the Universe itself.

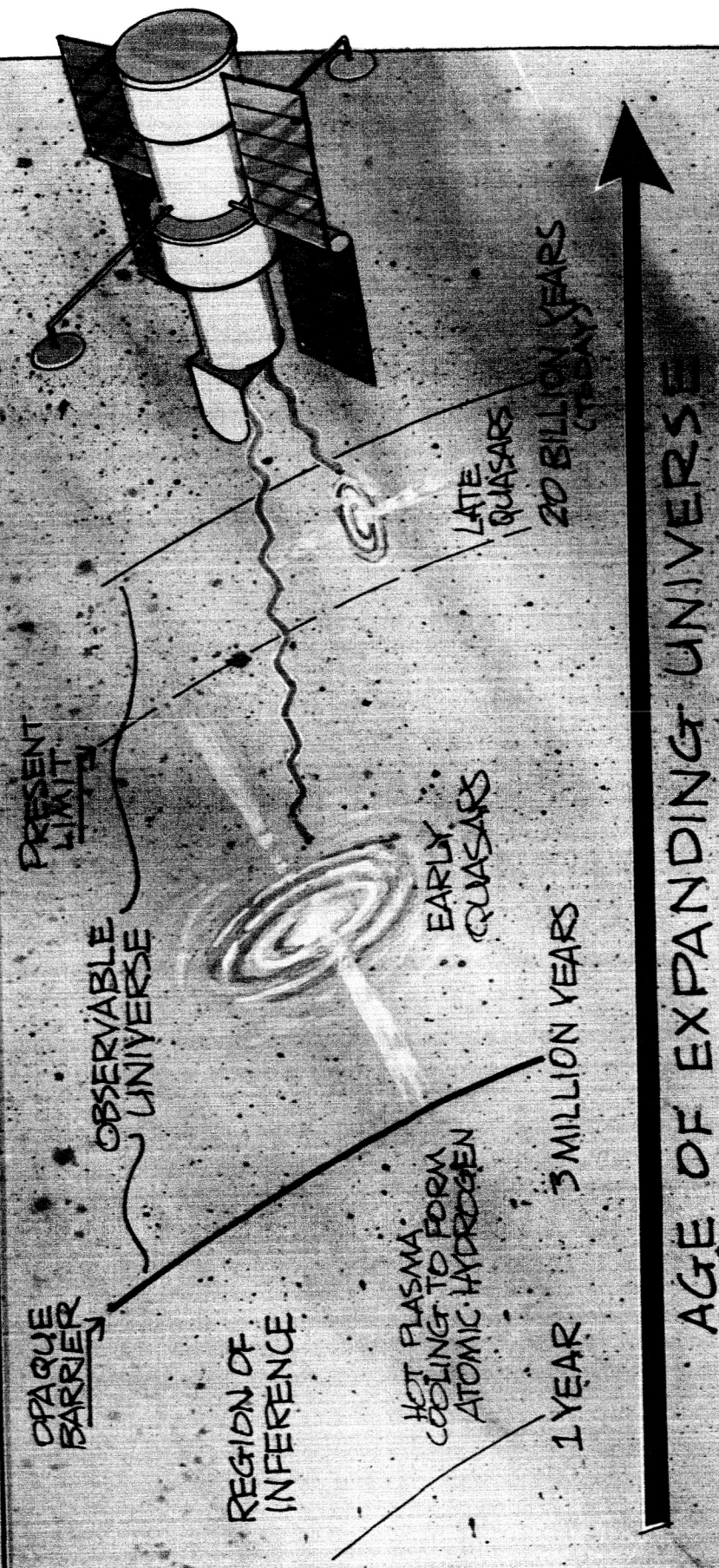
AXAF is also an important tool for studying individual quasars in detail. A quasar X-ray spectrum is a diagnostic to the physical processes producing the X-ray emission. Depending on the predominant energy-generating mechanism, it may be possible to deduce the elemental composition and temperature of the matter in quasars, the density and energy distributions of relativistic electrons and protons that may be producing X-rays, and the strength of the quasar's magnetic field.

The quasar problem challenges our current understanding of astrophysics. What causes the rapid variations in a quasar's luminosity from month to month, sometimes even from one hour to the next? Variability in the X-ray emission is generally more pronounced and more rapid than variability in the optical emission, indicating that X-rays are produced in the core of the quasar. How can so much X-ray energy be radiated from such a small source? Are quasars powered by matter falling into a black hole or by something yet to be discovered? AXAF will contribute to the solution of these riddles by discovering new quasars, monitoring their properties, and investigating their hidden energy sources.



This comparison of optical and X-ray images of the same field shows the power of X-ray astronomy for the detection and study of quasars. Although only one in a million extragalactic objects is a quasar, their prodigious X-ray emission clearly identifies quasars in deep X-ray images. Based on the known X-ray to optical luminosity ratio, we can predict that these quasars are amenable to study by the Hubble Space Telescope. Thus, the capabilities of AXAF and HST are ideally matched for observing quasars.

HOW DID QUASARS FORM AND EVOLVE? HOW DO THEY PRODUCE SO MUCH ENERGY?



AXAF WILL LOOK BACK IN TIME TO SEE QUASARS
IN EARLIER EPOCHS AND WILL STUDY THE
HIGH-ENERGY COMPONENT OF QUASAR EMISSION.

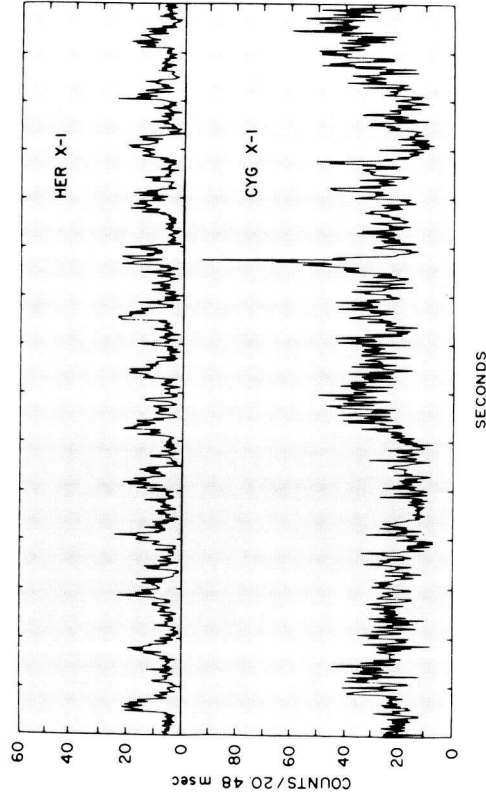
Einstein's theory of relativity predicts that some points of extraordinarily strong gravity, called black holes, exist in space. Matter and light fall into them under an irresistible gravitational pull. Because no light escapes the black holes themselves, they are very difficult to detect.

Black holes probably have a range of masses, some being much lighter than the sun and smaller than the Rock of Gibraltar while others are as heavy as a billion suns and yet smaller than the solar system. The most massive black holes may be the power sources for quasars, each releasing in one second the energy of a trillion suns. The smallest black holes could explode at any time, annihilating themselves in an enormous flash of X-rays lasting only a few seconds. A stellar black hole, five or ten times more massive than the sun, could siphon matter from the interstellar medium or from a companion star, producing X-rays as this matter falls into the black hole. In each case, the emitted X-rays are expected to have a distinctive signature.

An important challenge for astronomers today is to search for and confirm the existence of black holes. These objects are significant as possible sites of missing mass, as test laboratories for extreme gravitational interactions, and as test cases for general relativity theory. We are not completely sure that a real black hole has been observed, although previous X-ray missions have discovered several excellent candidates.

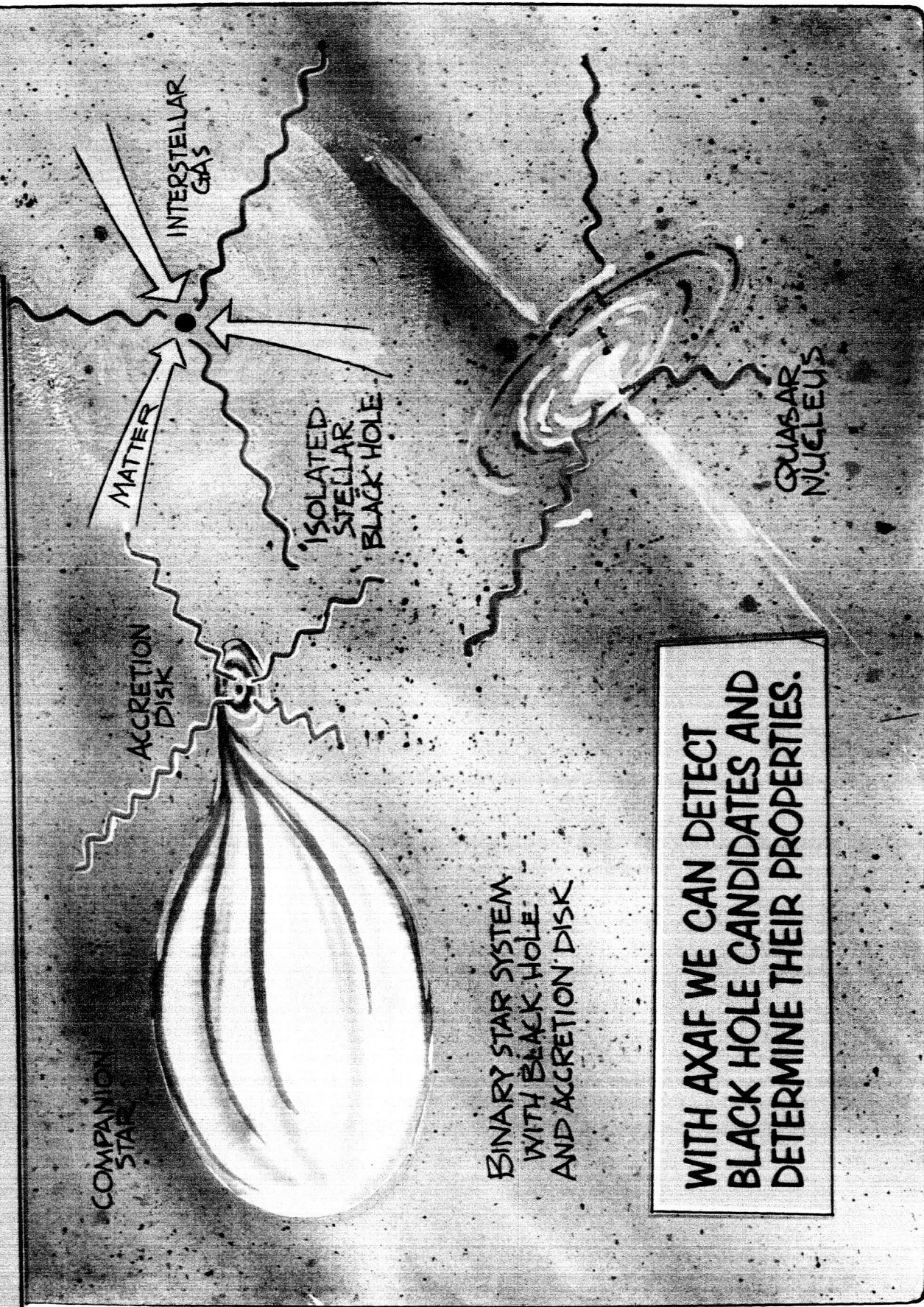
AXAF can contribute to the discovery and identification of black holes. Both the X-ray spectrum and the temporal behavior of the X-ray intensity of a variety of black hole environments are distinctive. AXAF will search the Universe for objects that match the theoretical predictions and then study their behavior in detail.

So far the only black hole candidates have been discovered with X-ray observations. AXAF will help to demonstrate whether or not these theoretical constructs really exist.



The figure contrasts the chaotic time variability of the X-ray emission from Cygnus X-1, the first black hole candidate, with the regularly pulsed emission from the X-ray binary Hercules X-1. It was the unusual X-ray temporal and spectral behavior that first drew astronomers' attention to Cygnus X-1 and led to its subsequent identification as a black hole.

WHAT KINDS OF BLACK HOLES EXIST?



WITH AXAF WE CAN DETECT
BLACK HOLE CANDIDATES AND
DETERMINE THEIR PROPERTIES.

The X-Ray Background

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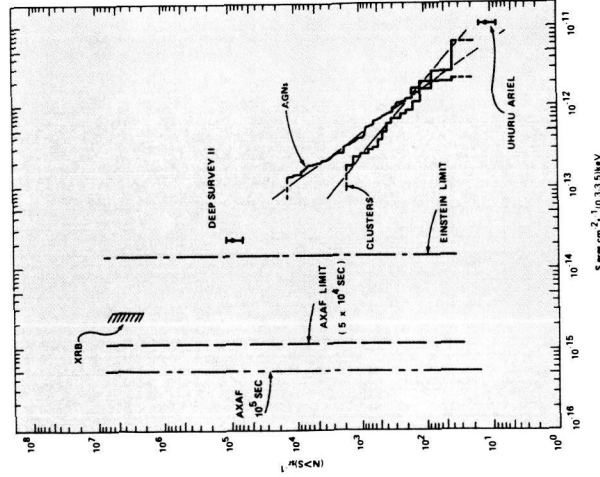
The first X-ray astronomy experiment discovered that the brightest X-ray source in the sky was an unexpected one: the sky itself. The entire Universe was aglow with X-rays. Everywhere we looked, we saw a diffuse X-ray background.

Today, almost 25 years later, we still do not know whether this background glow has a truly diffuse component or is a consequence of looking at many distant X-ray sources with an out-of-focus camera. The X-ray background cannot be caused entirely by known kinds of X-ray sources because there are not enough of them and they do not have the right spectral characteristics. Therefore, studying the background with AXAF guarantees profound discoveries.

The AXAF cameras will produce 10 times the detail seen in any previous X-ray pictures and will be able to detect sources 100 times fainter. If the X-ray background is due to the cumulative effect of many weak individual sources, these will be evident in high-quality, long-exposure AXAF images. These will have to be new types of X-ray sources or younger (more distant or fainter) versions of categories that we know but with different characteristics in order to produce the correct X-ray spectrum. If few sources appear in these images, then much of the X-ray background must be truly diffuse in origin, or evidence for even another new class of objects existing in the early stages of the Universe, or some combination. AXAF spectra will be a good indicator of the physical process that produces the X-ray background and will help us further understand any unresolved component.

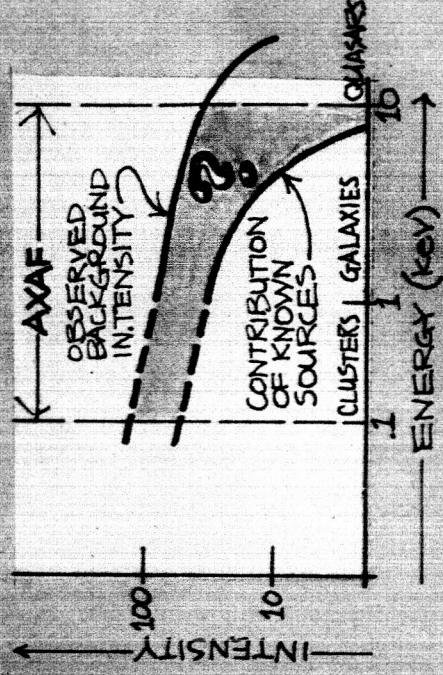
One result is certain: AXAF's ability to probe the diffuse X-ray background will lead to discoveries.

This figure shows the number of extragalactic X-ray sources with intensity greater than a given brightness S as a function of S. If the sources are uniformly distributed in a Euclidean universe, this number will be proportional to $S^{-3/2}$. The integrated contributions, however, cannot exceed the diffuse X-ray background. The limiting sensitivity of AXAF will take these observations to significantly weaker sources. Studies of the luminosity function of known objects (active galaxies and quasars) can explain much but not all of the diffuse X-ray background. The potential for discovery here is guaranteed as one must uncover either the evolutionary characteristics of known objects, and/or new classes of objects, and/or a truly diffuse component.



WHAT PRODUCES THE X-RAY BACKGROUND?

DISCRETE SOURCES
MADE UP OF KNOWN
CATEGORIES AND
ENTIRELY NEW CLASSES?



DISCRETE SOURCES
PLUS A TRULY
DIFFUSE COMPONENT?



AXAF WILL BRING THE X-RAY
BACKGROUND INTO SHARP
FOCUS ENABLING US TO
DETERMINE AND EXAMINE
ITS COMPOSITION.

Supernovae

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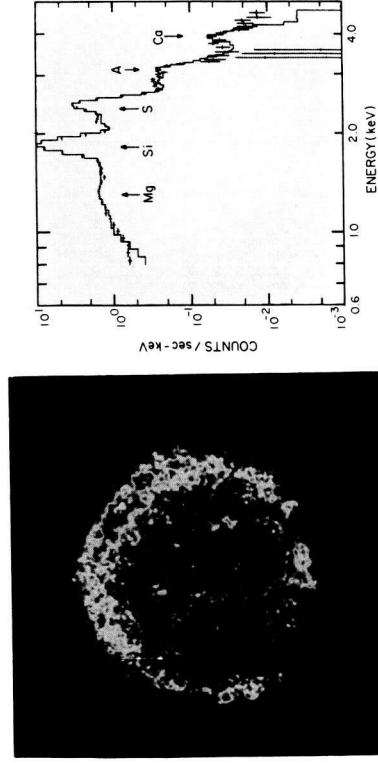
Stars pass through a life cycle from birth to death, some finishing with a violent explosion and others subsiding without spectacle. Stellar explosions are called supernovae. These explosions disperse throughout space the heavier chemical elements (such as oxygen and iron) formed in the central furnaces of stars. It is these heavy elements that make possible the existence of planets and life as we know it.

Supernova explosions spread the highly enriched chemical material in a huge cloud, or remnant, portions of which are very hot and strongly emit X-rays. AXAF X-ray spectra of these supernova remnants will show clear signatures of these chemical elements, telling us how much material stellar explosions eject and what the composition of this material is.

Sometimes when stars explode they leave a central object—a neutron star—no larger than Manhattan Island yet as massive as the sun. Neutron stars are born very hot and thus emit X-rays. A basic question remains unanswered: do all supernovae produce neutron stars? By looking at young supernovae (those explosions for which we have a historical record), AXAF will discover whether or not a neutron star has been left behind.

It is possible that sometimes a star is completely destroyed by its final explosion and no core is left or that what remains is a black hole rather than a neutron star. The X-ray spectrum and the variability of weak emission from a supernova site will indicate which is left. AXAF has the necessary sensitivity and spectral power to measure very weak sources and to distinguish between the signatures of black holes and neutron stars.

AXAF is an excellent diagnostic tool for examining the results of stellar explosions and for understanding the cosmic processes that produced the chemical elements on Earth today.



An X-ray image of the supernova whose visible light outburst was recorded by Tycho Brahe in 1572 is matched with the energy spectrum for the entire remnant. A key test of theoretical models of supernova explosions involves not only searches for any remaining compact objects but also a check on the prediction of large amounts of iron in the remnant. The HEAO-2 spectrum shows features due to silicon, sulphur, argon, and calcium produced in the progenitor star and by the supernova explosion. Only AXAF, however, permits a search for the expected iron emission between 6 and 7 keV. AXAF will also obtain the spatial distribution of the various elements ejected in the explosion; this information can be used to understand the supernova process.

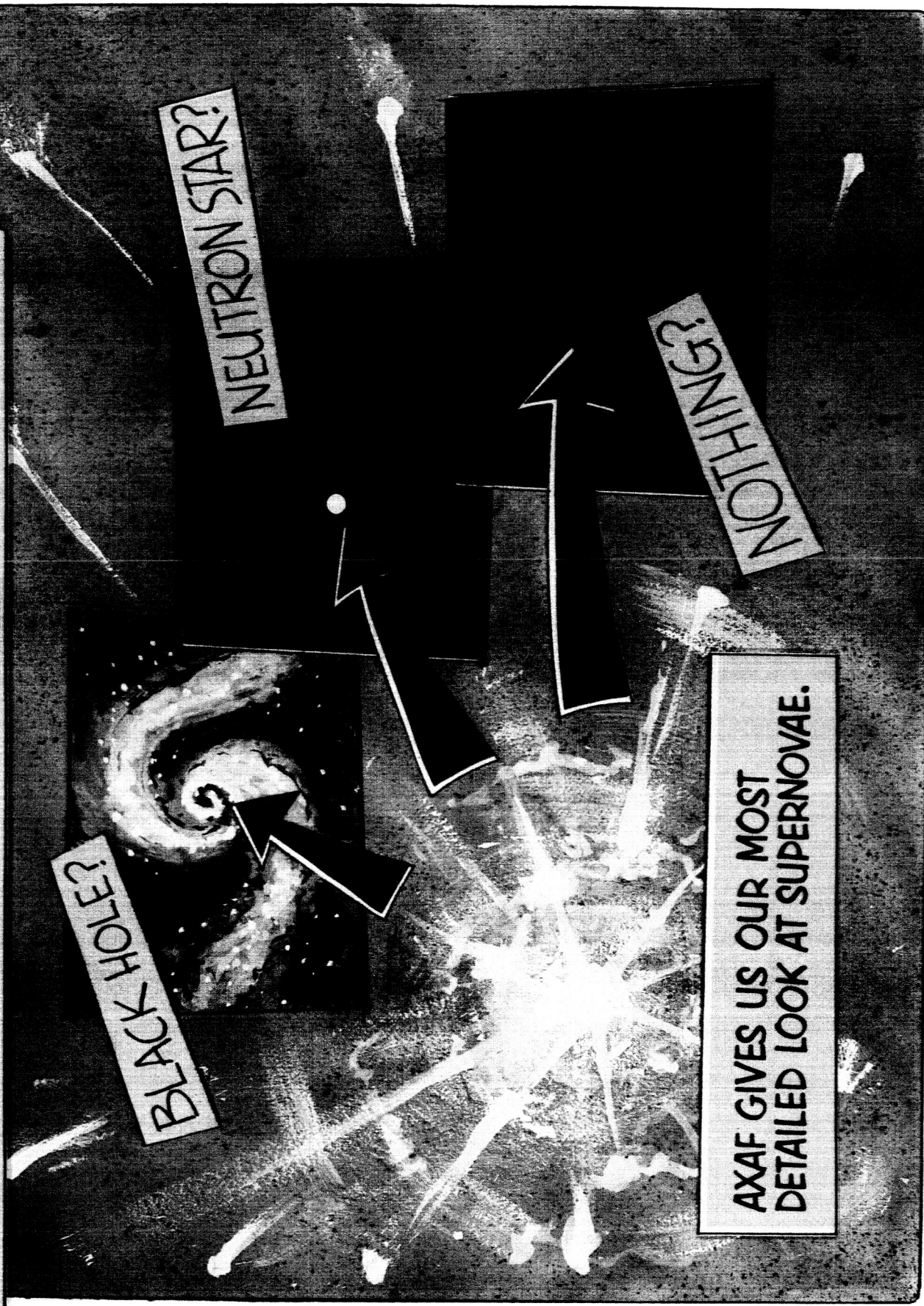
WHAT REMAINS AFTER STARS EXPLODE?

BLACK HOLE?

NEUTRON STAR?

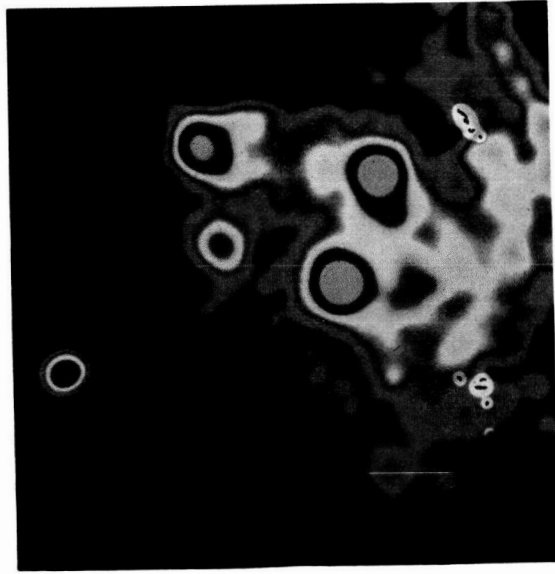
NOTHING?

AXAF GIVES US OUR MOST
DETAILED LOOK AT SUPERNOVAE.



Normal Stars

24



The unexpected existence of hot, X-ray emitting atmospheres around all types of stars has been revealed through X-ray observations such as this one of an association of massive stars in the constellation Carina. Conventional wisdom held that only stars with internal convection processes like those of the sun could generate X-ray emitting coronae. Previous X-ray observations provided only total luminosity and crude spectra of a few samples of such objects, whereas AXAF will perform detailed observations of many stars to understand this puzzling phenomenon.

The sun was the first astronomical X-ray source to be discovered. It appears very bright because it is so close. However, on an absolute scale the sun and other stars like it are weak X-ray sources. It thus requires the power of AXAF to study the X-ray emission from stars like the sun.

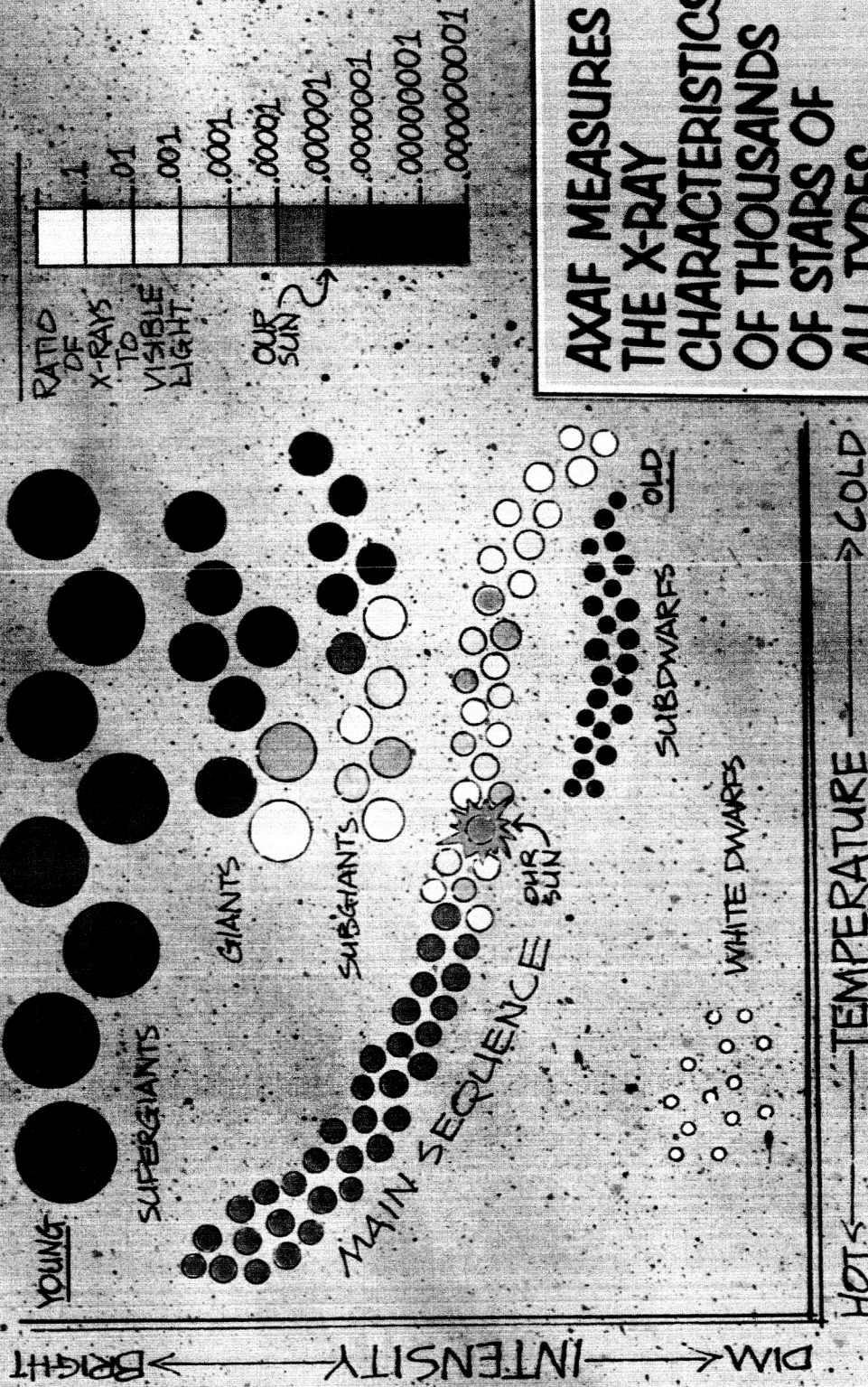
AXAF's prototype, HEAO-2, unexpectedly discovered that many classes of stars have an extremely hot outer layer (a corona) like that of our sun. Temperatures in the corona reach millions of degrees, making it a source of X-rays. The corona is distant from the hot core of a star, and there is an intervening cool layer of gas between the core and the corona. What heats the corona and how is the high temperature maintained? The HEAO-2 data were very limited and in most cases measured only the strength of X-ray emission. AXAF is capable of significantly increasing our knowledge of stellar coronae by accurately determining the chemical composition and temperature of many coronae.

Although AXAF will not look directly at the sun, it will be able to view thousands of other stars and obtain a large statistical sample of their characteristics. Detailed measurements of many stars will enable us to determine which parameters—temperature, magnetic fields, rotation rates—are most important in producing X-rays from stars. This information will shed light on the processes that heat stellar coronae, including that of our own sun. Optical astronomers have spent many decades working on such problems and giving us a much better understanding of the sun and our galaxy. X-ray surveys of stars will be equally enlightening.

Better understanding of high-energy processes on the sun and other stars is also relevant to efforts on Earth to confine extremely hot, magnetized gases. Astrophysical observations are beneficial to plasma physics research and therefore to attempts to produce and control nuclear fusion reactions.

AXAF will study many types of stars, revealing information that is of paramount importance to solar, stellar, and plasma physics research.

HOW DO OTHER STARS COMPARE WITH THE SUN?



The Universe is a laboratory for probing new physical theories. The conditions just after the Big Bang represent energies and densities far greater than the most ambitious particle accelerators conceivable. Nevertheless, these conditions are covered by basic physical theories. Current theories of physics predict the existence of exotic new particles such as axions, photinos, and massive neutrinos. These theories also lead to predictions of the nature and distribution of dark matter in the Universe.

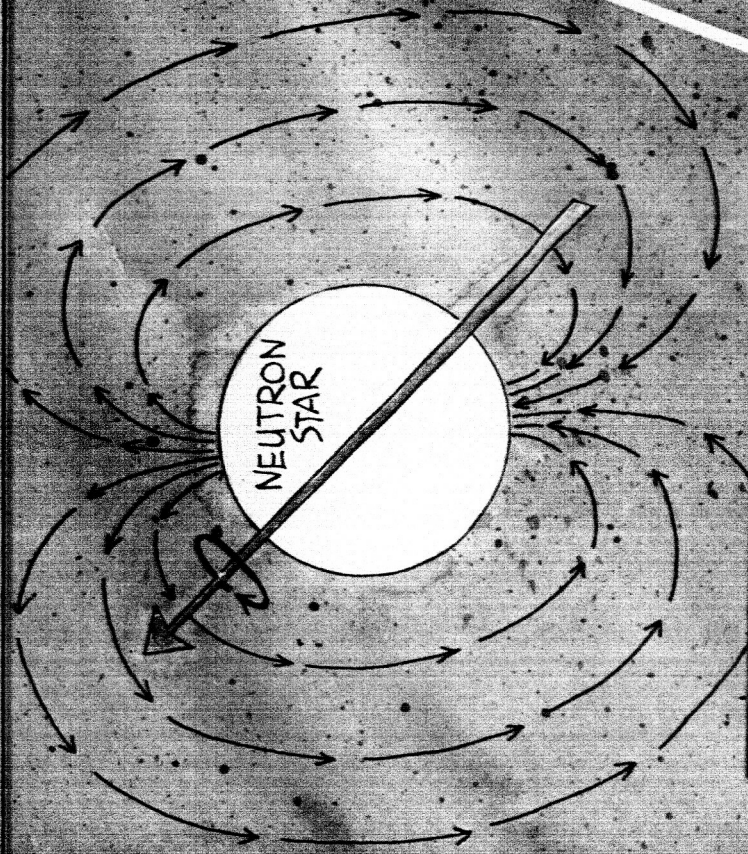
Studies with AXAF will test these theories. AXAF can locate and measure the mass of dark matter in galaxies and clusters of galaxies, observe the evolution of these objects, and directly probe the large scale structure of the Universe to provide clues to the nature of dark matter. Is most of the matter "hot" (massive neutrinos) or "cold" (axions, photinos)? We don't know.

The existence of the exotic particles can also be studied in other astrophysical settings. If magnetic monopoles (another exotic particle) exist, they may affect the cooling rates and X-ray spectra from neutron stars which can be observed with AXAF. Proving the existence of magnetic monopoles could invalidate most current cosmological theories, a truly revolutionary result.

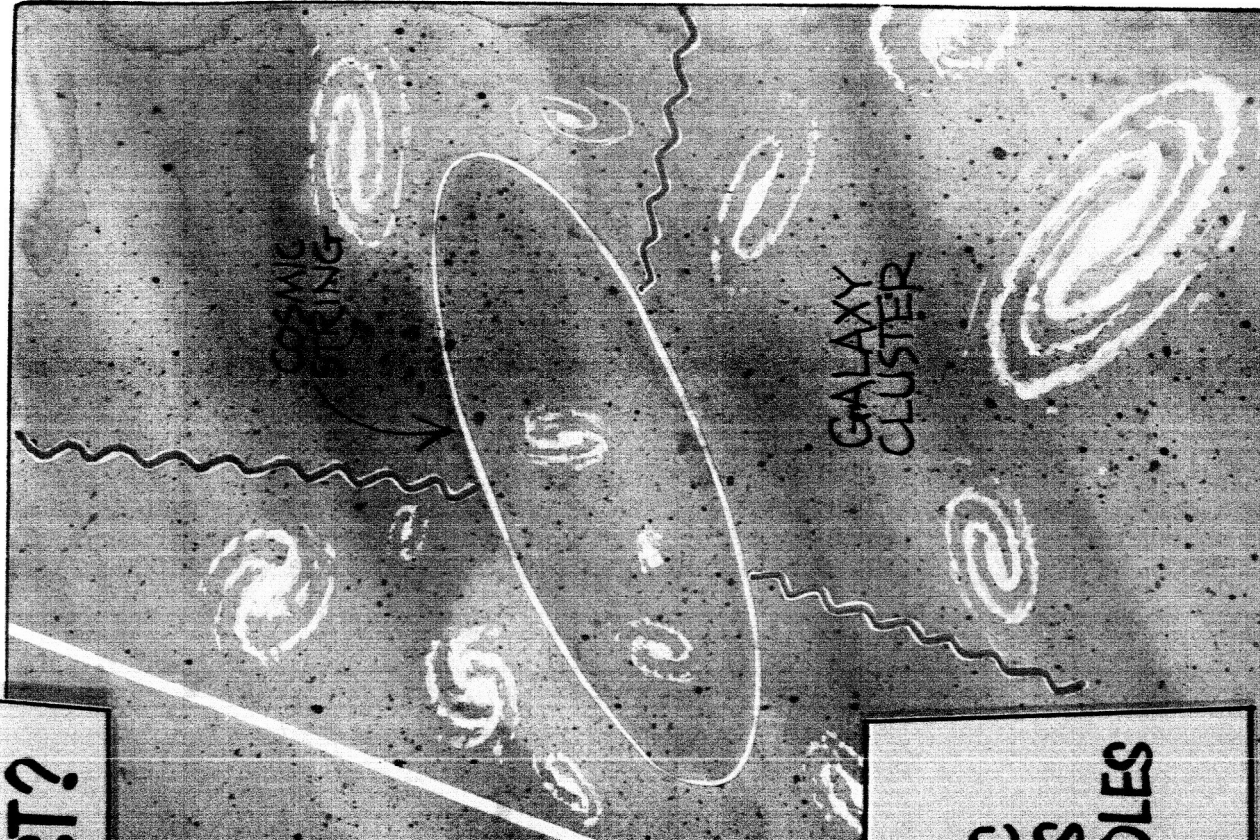
It may even be possible, although this is very speculative, to directly measure and detect the X-ray emission produced by some of the exotic particles as they interact with normal matter. One such example might be X-radiation from cosmic strings. These are theorized to be relics of the formation of the Universe, far thinner than a subatomic particle, yet with masses of billions of tons per inch of length. Cosmic strings might be detected as X-ray sources when they interact with the hot gas filling the space between clusters of galaxies.

These are just a few examples of AXAF's relevance to basic physics. A new and better understanding of nature always results when new tools for gathering data open new information channels or extend known ones. AXAF has both these attributes and combines them with the ability to investigate the extreme physical conditions that produce X-rays. AXAF provides a unique opportunity to test the limits and basis of physical theories.

DO EXOTIC PARTICLES EXIST?



AXAF MAY DETECT EVIDENCE FOR THE EXISTENCE OF COSMIC STRINGS AND EXOTIC PARTICLES SUCH AS AXIONS AND MONOPOLES IN NEUTRON STARS.



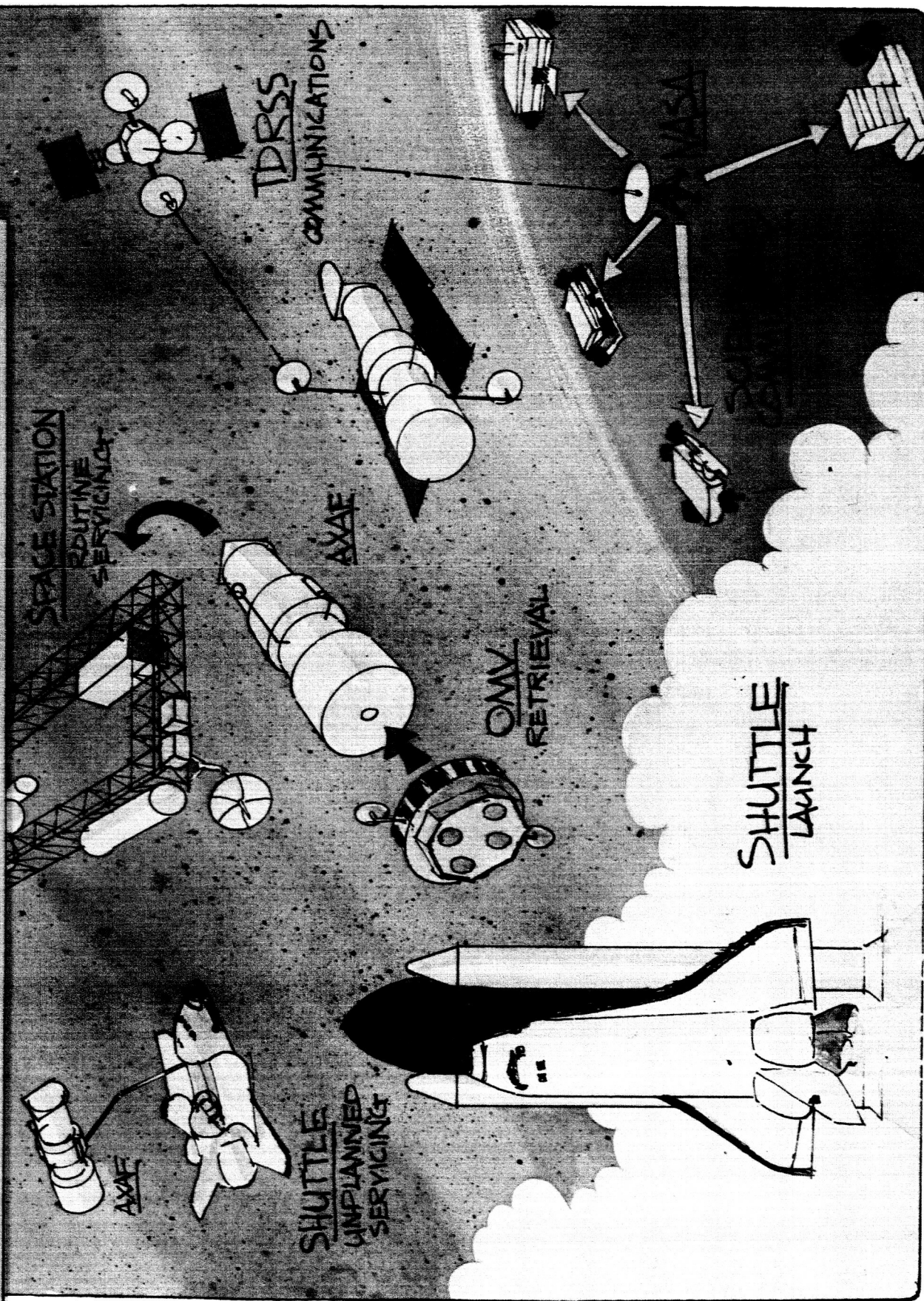
The United States is uniquely poised to lead the international exploration of space with AXAF and the other Great Observatories. The United States pioneered and developed X-ray astronomy, making almost all the major technological and scientific advances in this field. AXAF is the next step in a well-planned and successfully executed series of initiatives in high-energy astrophysics.

AXAF makes effective use of the most important capabilities and resources that NASA and the nation's space science community offer. The infrastructure to support AXAF is in place. AXAF is to be launched as a Space Shuttle payload into orbit near the Space Station. With the aid of the Orbital Maneuvering Vehicle, it can be serviced in space for prolonged operation. AXAF will utilize advanced NASA systems such as the Tracking and Data Relay Satellite System (TDRSS) and take full advantage of the experience and capabilities of the NASA field centers.

The impact of AXAF on the research community will be still greater than the prototype HEAO-2 mission. The HEAO-2 guest observer and data bank programs involved more than 500 scientists from some 60 research institutions in the United States and 50 institutions abroad. This widespread interest in X-ray astronomy enhances the climate of international scientific cooperation.

The AXAF program signals the end of a decade-long hiatus in American X-ray astronomy missions and the resumption of leadership in a field the U.S. introduced and developed. The United States has all the necessary resources to implement AXAF and do it well.

MAKING USE OF AMERICA'S RESOURCES



AXAF: An Uncomplicated Spacecraft

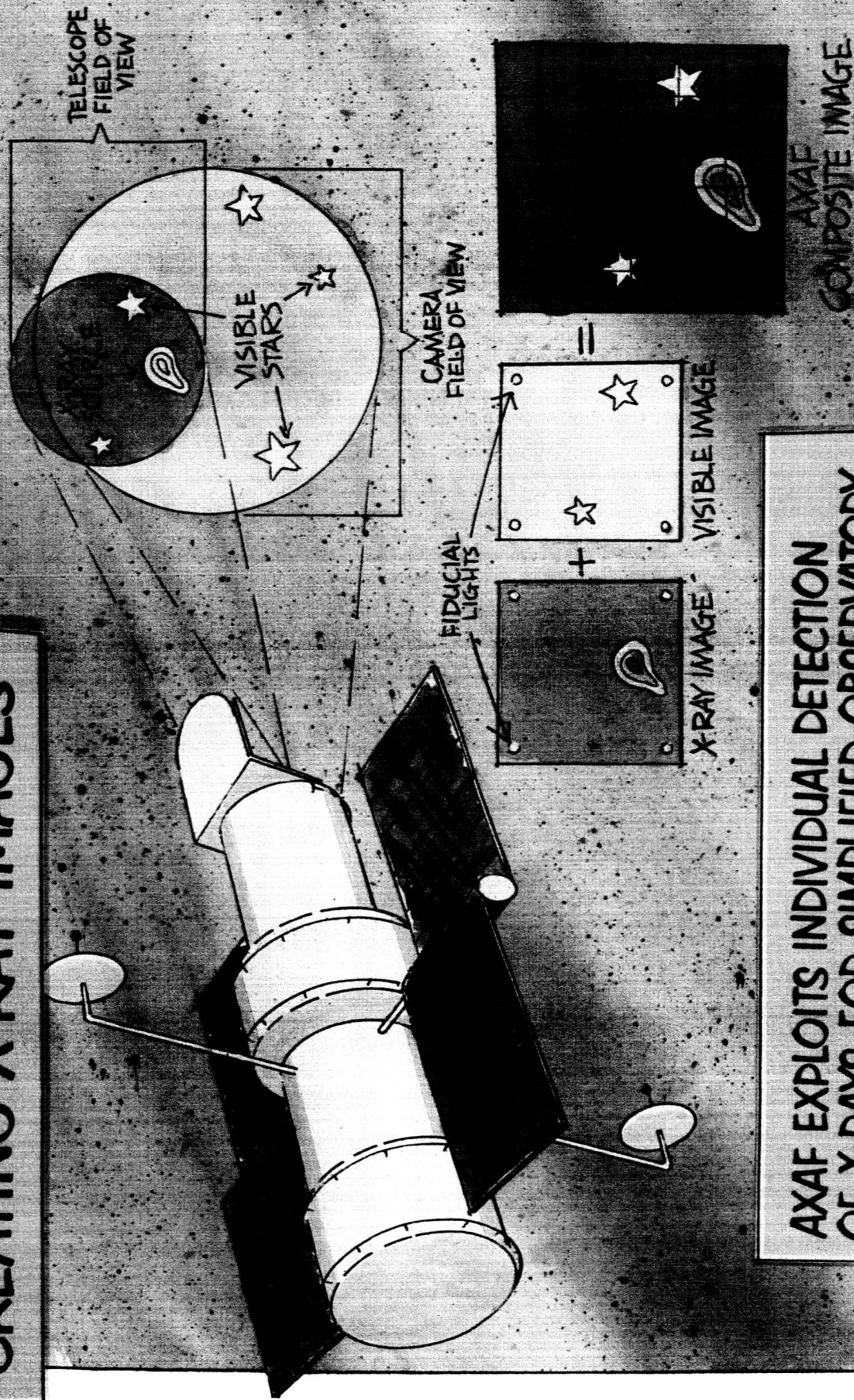
30

The AXAF spacecraft design is surprisingly modest. The data rates are small, less than 32 thousand bits per second. Further, AXAF does not require the complexity of "real time" operation which allows the astronomer to see the results of an observation immediately. Rather, all observations are preplanned, the data recorded on AXAF, telemetered to the ground and analyzed after the fact.

One greatly simplifying consequence of the low data rates and the fact that X-ray instruments record each detected X-ray is that there is practically no need either to stabilize the direction that the telescope is pointing or to maintain a highly rigid structure between the telescope and the instruments. Visible light telescopes must be stabilized to a degree much better than their angular resolution; otherwise the image is blurred. In contrast, the AXAF scheme does not require this precise stabilization.

An electronic visible light camera mounted rigidly to the telescope photographs the sky and, by means of relay optics, the positions of fiducial lights rigidly mounted to the X-ray detectors. The X-ray detectors, of course, locate the X-rays relative to the fiducial lights. The X-ray image then may be reconstructed on the ground, and after the fact, during data processing. This method of obtaining images greatly simplifies the design of the optical structure and the spacecraft pointing control system. For example, the region over which the line of sight may wander during an AXAF observation is some 18 million times larger than for the Hubble Space Telescope, which operates in visible light.

CREATING X-RAY IMAGES



AXAF EXPLOITS INDIVIDUAL DETECTION
OF X-RAYS FOR SIMPLIFIED OBSERVATORY
DESIGN & OPERATION.

The Advanced X-Ray Astrophysics Facility has evolved from the highly successful HEAO program of the 1970's. As a result, the technology and research concept for AXAF have already been tried and proven. All the necessary elements for AXAF are in place, and this important program can now begin.

The heart of AXAF is a set of mirrors that focus incoming X-rays onto detectors where they are recorded for analysis. X-rays can be reflected from highly polished surfaces if they only graze the surface. These surfaces must be very smooth, with irregularities measured in diameters of atoms, to obtain the best performance. The AXAF telescope consists of six nested pairs of cylindrical surfaces, the first parabolic and the second hyperbolic. Two reflections are necessary to focus all X-rays within the field of view.

The AXAF telescope is an advanced version of the HEAO-2 system, with much larger collecting area and much better resolution. NASA has just completed a mirror assessment program to demonstrate that the technology for AXAF exists. A small X-ray telescope built to AXAF specifications proved that both the angular resolution and the surface smoothness were achievable.

Four different X-ray detector systems have been selected for possible use in AXAF. Two X-ray cameras with complementary sensitivity in different parts of the X-ray spectrum will provide sharp images of cosmic X-ray sources. Two spectrometers will dissect the X-ray spectrum to identify and measure the unique signature of each X-ray source. These instruments are a blend of old and new technology; two have evolved from HEAO but take advantage of recent advances in detector technology, and two are pioneering developments which will also have medical and commercial applications beyond their use for AXAF.

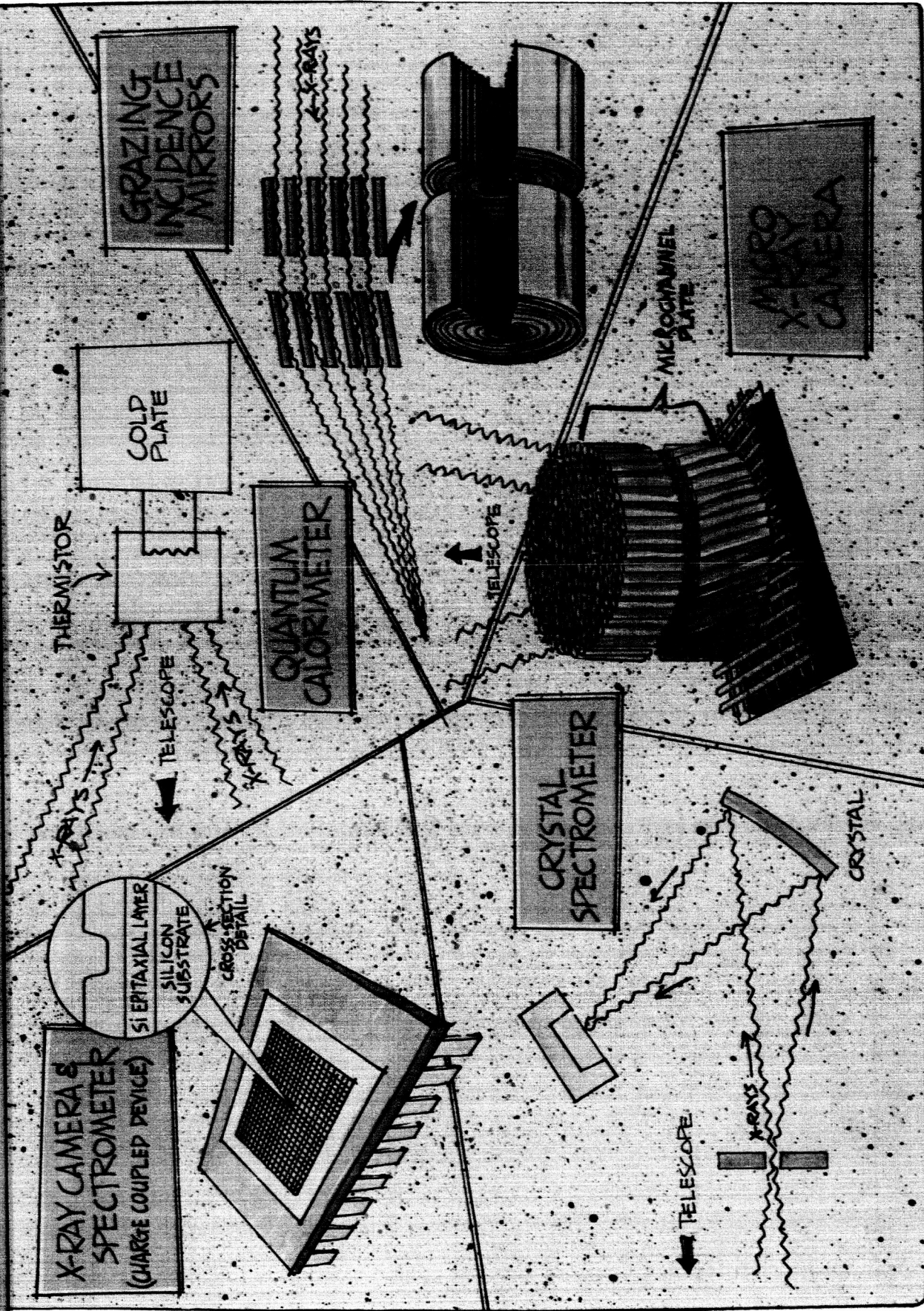
Working with the scientific community, NASA has been preparing for the AXAF mission since 1977. In 1983, two competing corporations began detailed preliminary designs for AXAF. These contractors and their team members were involved in the HEAO, GRO, and HST programs. The AXAF project is also managed by the same NASA field center responsible for HEAO and HST so that an experienced management base is in place.

Thorough definition and design studies have been completed, and the technology is available now. AXAF is ready and can be used to best advantage now, in planned partnership with the other Great Observatories.

X-RAY OPTICS AND FOCAL PLANE INSTRUMENTS

The diagram illustrates the components and layout of an X-ray Free Electron Laser (XFEL) system. Key elements include:

- GRAZING INCIDENCE MIRRORS:** Located at the top, these mirrors reflect the X-ray beam.
- COLD PLATE:** A component used for cooling, positioned below the mirrors.
- THERMISTOR:** A temperature-sensing device connected to the cold plate.
- QUANTUM CALORIMETER:** A device for measuring the energy of the X-ray beam.
- CRYSTAL SPECTROMETER:** A device for dispersing the X-ray beam into its constituent wavelengths.
- CRYSTAL:** A component used for focusing or dispersing the beam.
- TELESCOPE:** Used for observing the beam's path and focusing.
- MICROCHANNEL PLATE:** A device for amplifying the signal or focusing the beam.
- MICRO X-RAY CAMERA:** A camera for capturing high-resolution images of the beam.
- X-RAY CAMERA & SPECTROMETER (CHARGE COUPLED DEVICE):** A device for capturing and analyzing the X-ray beam.
- CROSS-SECTION DETAIL:** A detailed view of the Siemtacial Layer and Silicon Substrate.



AXAF and the Space Station

34

The United States is now committed to the bold venture of establishing a permanent presence in space for scientific and commercial operations. Our nation's future in space will be centered on the Space Station.

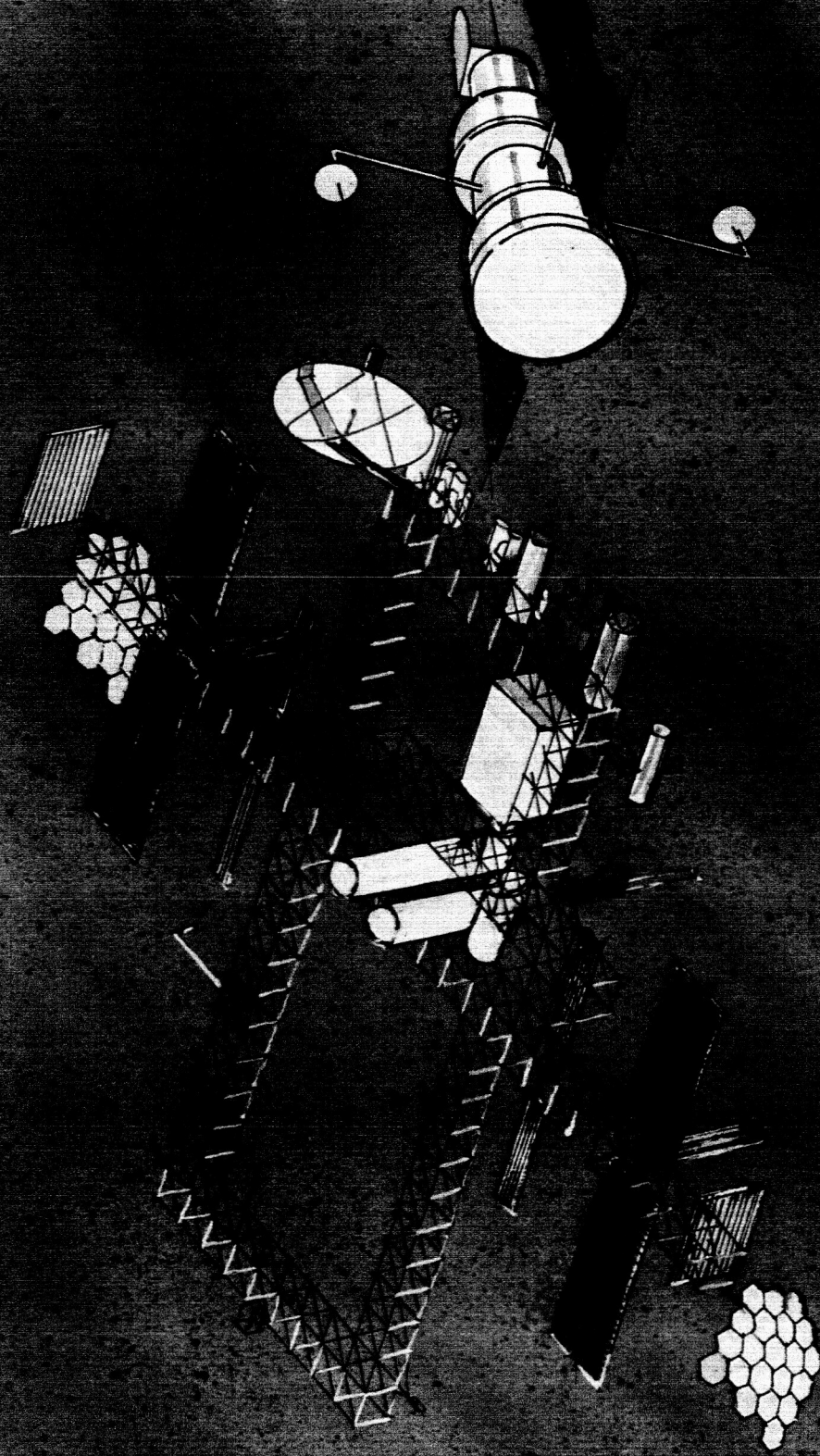
The Space Station will be important as a service center for AXAF. Current planning calls for use of the Shuttle for emergency servicing and use of the Space Station for routine servicing and replacement of instruments. With the assistance of on-site astronauts, the observatory can be redeployed with an extended operational life.

AXAF is particularly well suited for operations in the Space Station era. A long-lived mission maximizes scientific return on our investment in AXAF. Uninterrupted X-ray observations over many years will enable scientists not only to make discoveries but also to do the detailed follow-up studies that lead to genuine understanding. AXAF's guarantee of a long-term mission is maintenance and servicing at the Space Station.

While orbital servicing is the strongest link between AXAF and the Space Station, the two facilities may also be compatible logistically. Standardized parts and modules, to be supplied by the Space Station program for use in AXAF and other programs for improved efficiency and economy, are under study.

The scientific merit of a long-term X-ray astronomy mission is clear, and the Space Station and Shuttle guarantee the feasibility. AXAF is part of our nation's commitment to a permanent presence in space.

SERVICING WITH THE SPACE STATION



**ORBITAL SERVICING GUARANTEES A LONG-LIVED
AXAF MISSION AND MAXIMUM SCIENTIFIC RESULTS.**

A generation ago, the fields of X-ray astronomy and high-energy astrophysics did not exist. Telescopes had not yet been placed on spacecraft for an unobscured view of the cosmos, and few astronomical windows outside the spectral band of visible light had been opened.

In just 25 years, we have progressed from a naive view of a static Universe to knowledge of the dynamic Universe revealed to us in X-rays. We are now at the threshold of a golden age of observation and discovery. This rapid progress was possible with the mastery of spaceflight and with technological advances that resulted in ever more sensitive and more powerful telescopes and detectors.

Periodically, the government asks the National Academy of Sciences to recommend priorities for scientific programs. AXAF was ranked as the #1 priority among major programs in the Academy's last report on astronomy and astrophysics. This recommendation was supported by the Academy's recent report on physics which specifically recognized the importance of AXAF for the fields of plasma physics and cosmology. These recommendations and endorsements reflect strong support within the scientific community for a mission that will combine discovery with detailed study. AXAF will answer questions raised by previous missions and will inevitably make new discoveries.

Besides its intrinsic scientific merit as a tool for expanding our knowledge of the Universe, AXAF is a necessary part of the Great Observatories program and is a powerful tool in basic physics research. The United States is in a unique position of leadership and preparedness for a successful AXAF mission; the experience, expertise, and resources established through previous space science missions and the AXAF planning effort are ready and available.

The best time for AXAF to fly is with the other Great Observatories in a coordinated exploration of the Universe across the electromagnetic spectrum. That time is now.

SEIZING THE OPPORTUNITY NOW!

1962
DISCOVERY
OF FIRST
X-RAY
SOURCE

1960's
ROCKETS

1970
WHURU
(SAS-1)

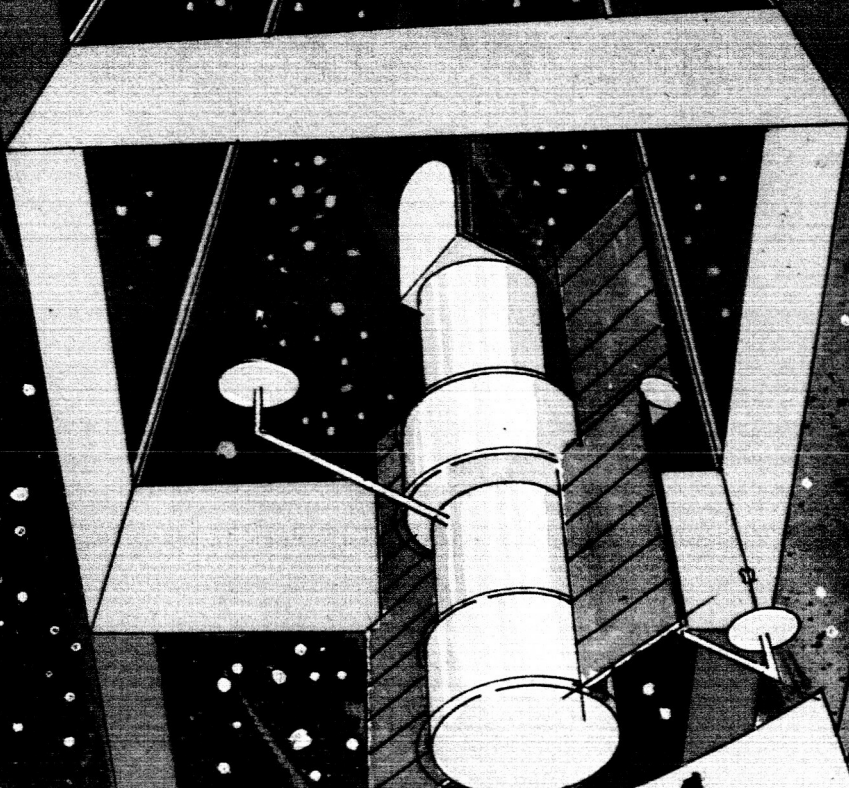
1971
OSO-7

1975
SAS-3
OSO-8

NOW
AXAF

1980/2
HEAO-2

1977
HEAO-1



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